TEL AVIV UNIVERSITY

Information Security – Theory vs. Reality

0368-4474, Winter 2015-2016

Lecture 3:
Power analysis, correlation power analysis

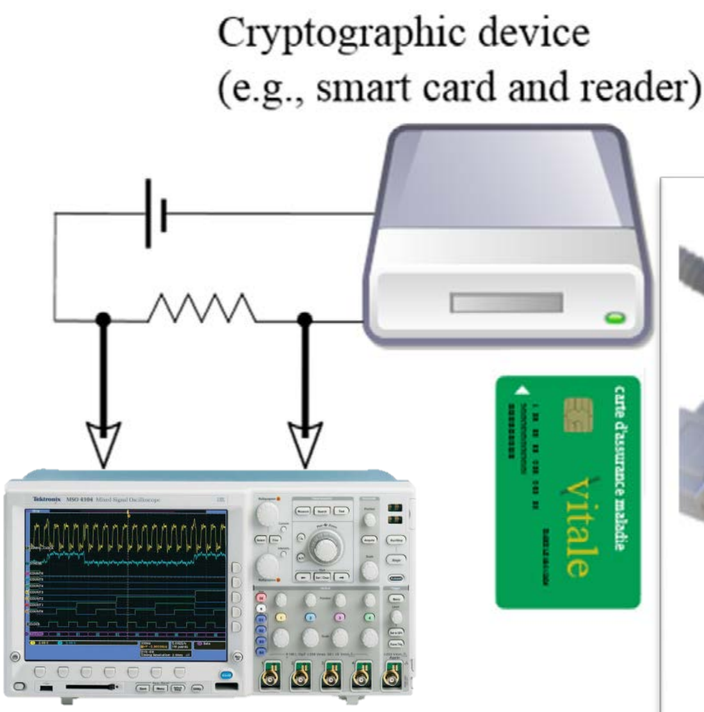
Lecturer:
Eran Tromer

Power Analysis

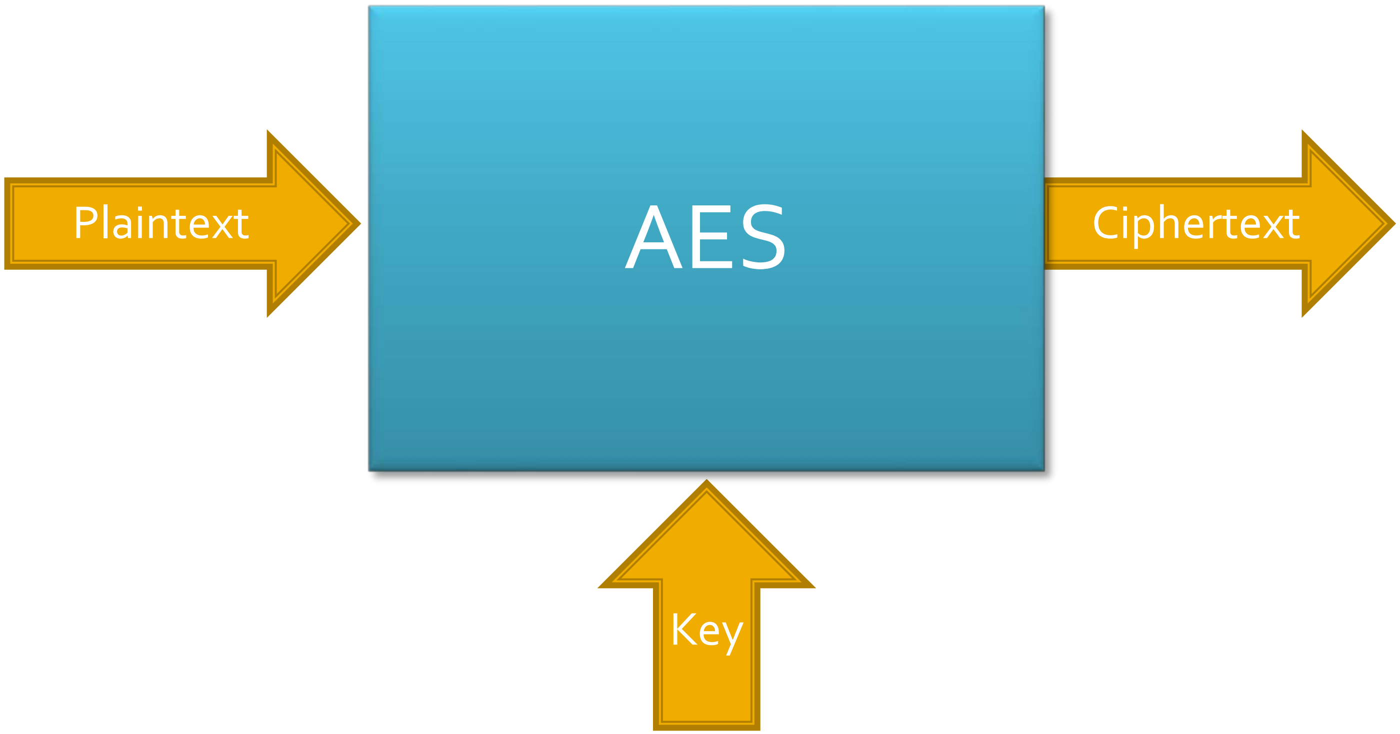
Simple Power Analysis
Correlation Power Analysis
Differential Power Analysis

Power analysis

- Power analysis: measure device’s power consumption.



The AES Cipher

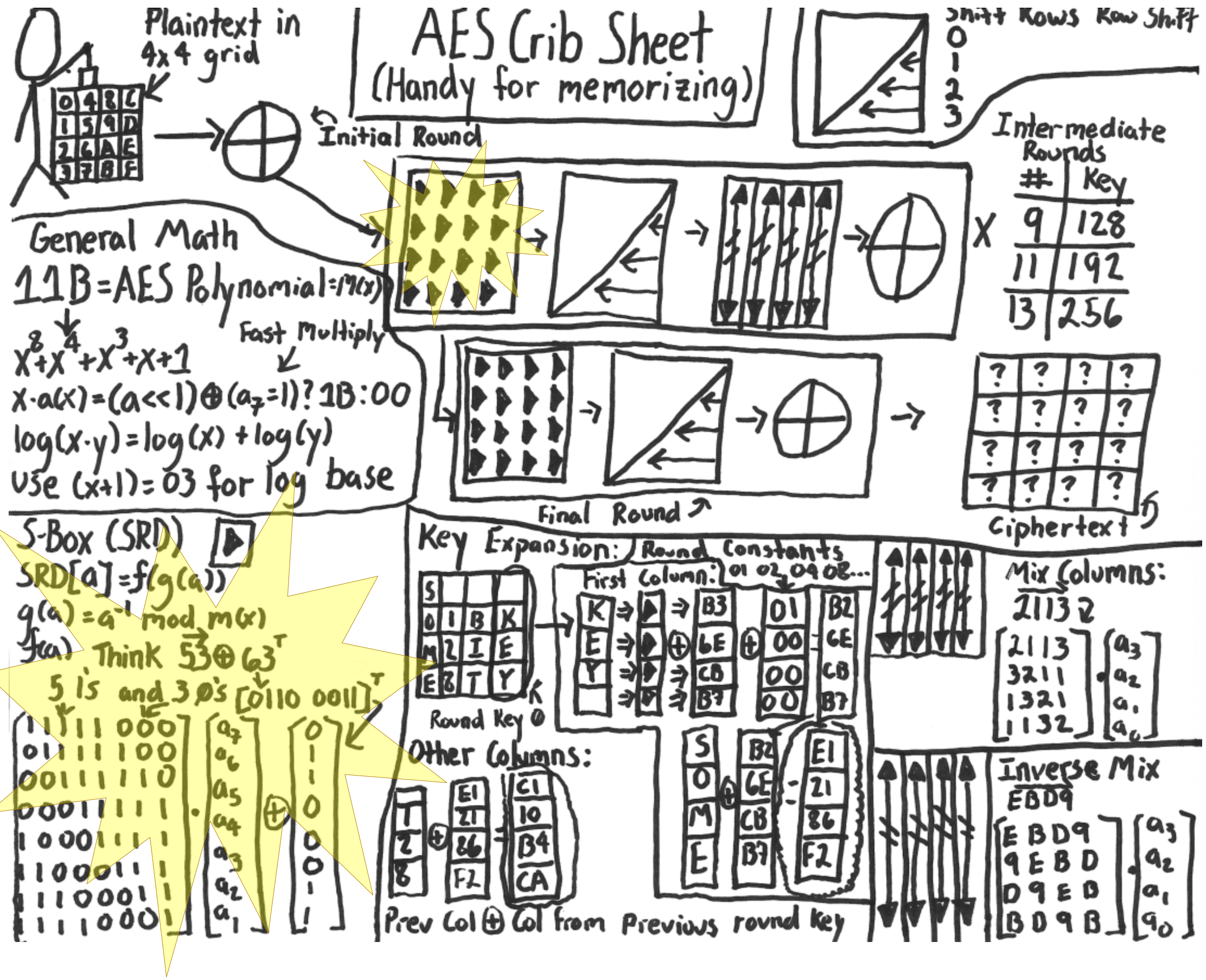


AES symmetric cipher: Lookup-based implementation

```
char p[16], k[16];                              // plaintext and key
int32 Col[4];                                   // intermediate state
const int32 T0[256],T1[256],T2[256],T3[256]; // lookup tables
...

/* Round 1 */
Col[0]← T0[p[ 0]⊕k[ 0]] ⊕ T1[p[ 5]⊕k[ 5]] ⊕
        T2[p[10]⊕k[10]] ⊕ T3[p[15]⊕k[15]];
Col[1]← T0[p[ 4]⊕k[ 4]] ⊕ T1[p[ 9]⊕k[ 9]] ⊕
        T2[p[14]⊕k[14]] ⊕ T3[p[ 3]⊕k[ 3]];
Col[2]← T0[p[ 8]⊕k[ 8]] ⊕ T1[p[13]⊕k[13]] ⊕
        T2[p[ 2]⊕k[ 2]] ⊕ T3[p[ 7]⊕k[ 7]];
Col[3]← T0[p[12]⊕k[12]] ⊕ T1[p[ 1]⊕k[ 1]] ⊕
        T2[p[ 6]⊕k[ 6]] ⊕ T3[p[11]⊕k[11]];
...
```

AES symmetric cipher: “Algebraic” implementation



Source: http://www.moserware.com/2009/09/stick-figure-guide-to-advanced.html

AES symmetric cipher: "Algebraic" implementation in code

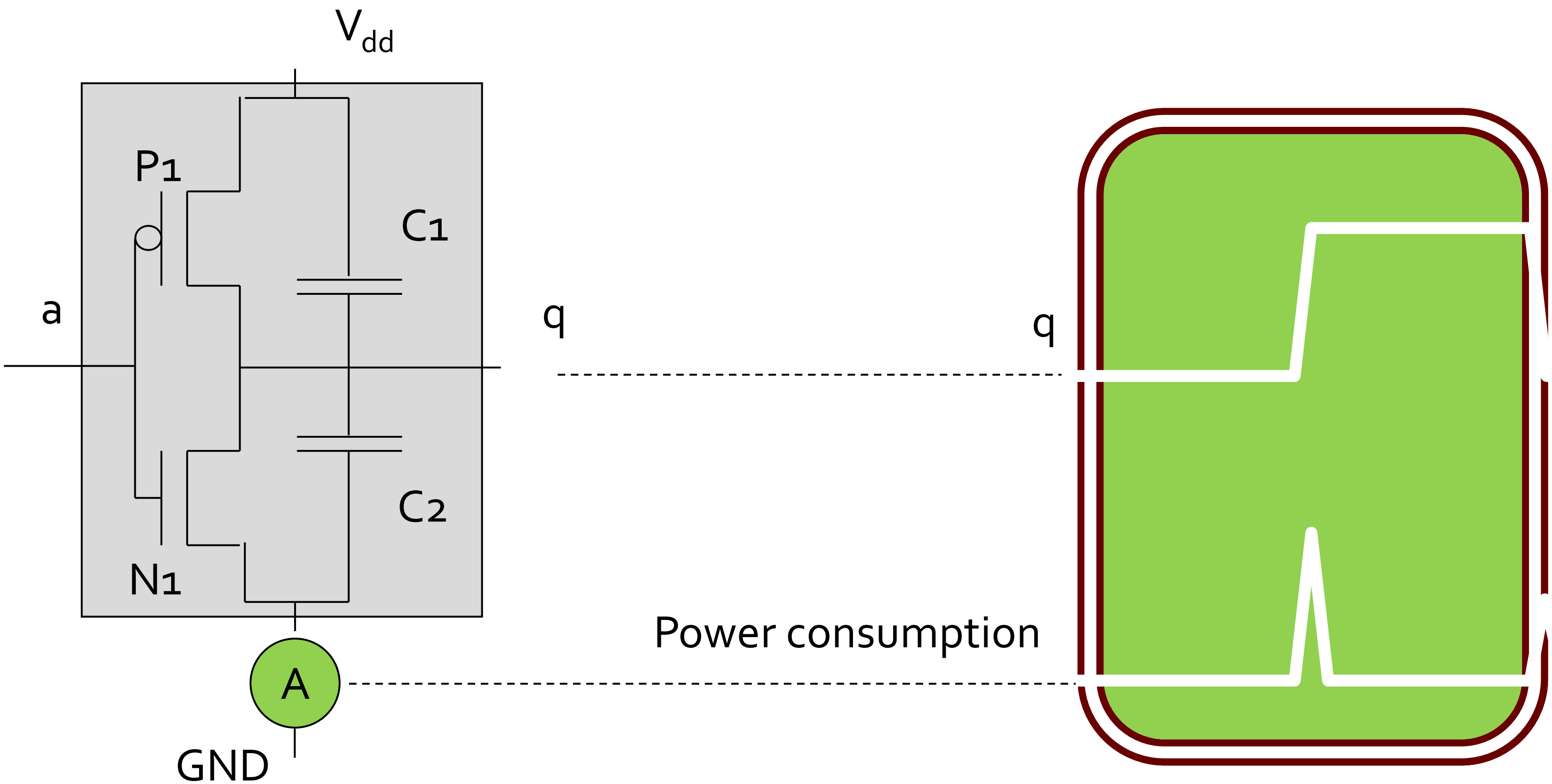
```
void AESEncrypt( u8 input[16], u8 output[16] ) {
[…]
  for (r=1; r<=9; r++)
  {
    ByteSub(state);
    ShiftRow(state);
    MixColumn(state);
    KeyAdd(state, roundKeys, r);
  }
[…]
```

Source: http://users.ece.utexas.edu/~gerstl/ee382v-ics_f09/soc/tutorials/System_C_Code_Examples_2/date04_examples/cosimulate/sw_only/

Theory of power analysis

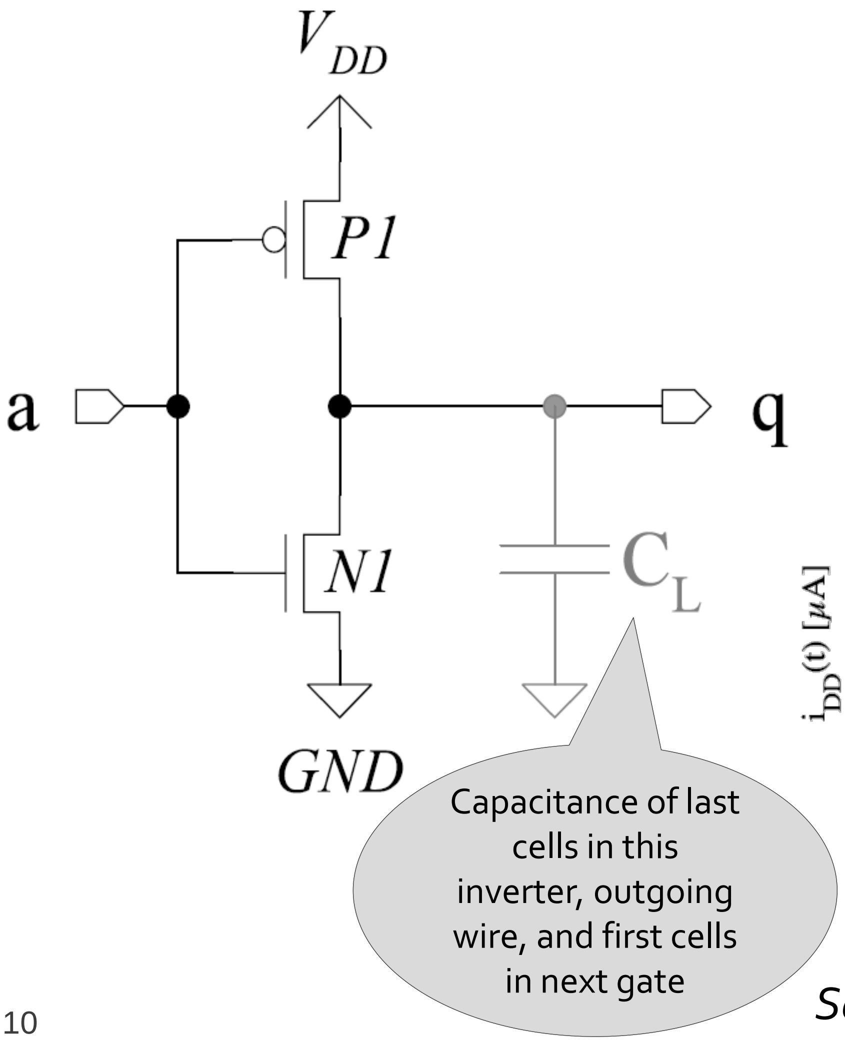
- Power consumption is **variable**
- Power consumption depends on **instruction**
- Power consumption depends on **data**

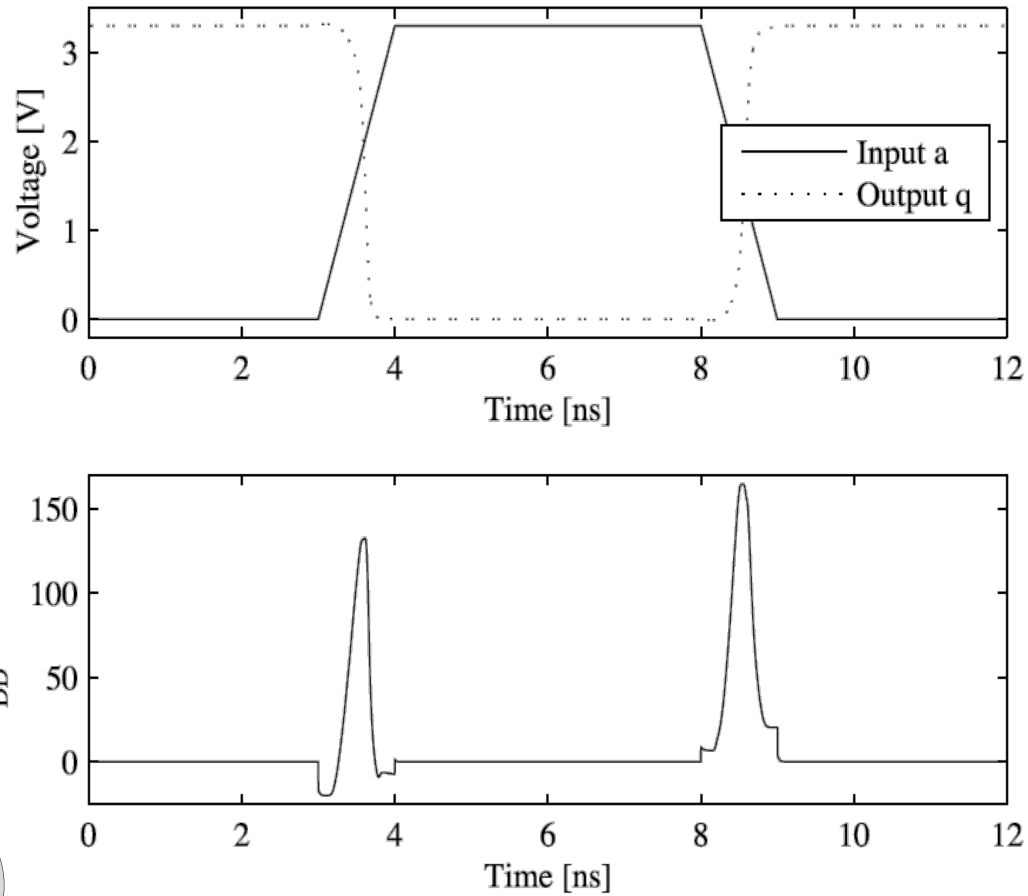
Data-dependent power consumption: gate capacitance



- The power consumption of a CMOS gate depends on the data:
  - q: 0->0 almost no power consumption
  - q: 1->1 almost no power consumption
  - q: 0->1 high power consumption (proportional to C2)
  - q: 1->0 high power consumption (proportional to C1)

Data-dependent power consumption: wire capacitance





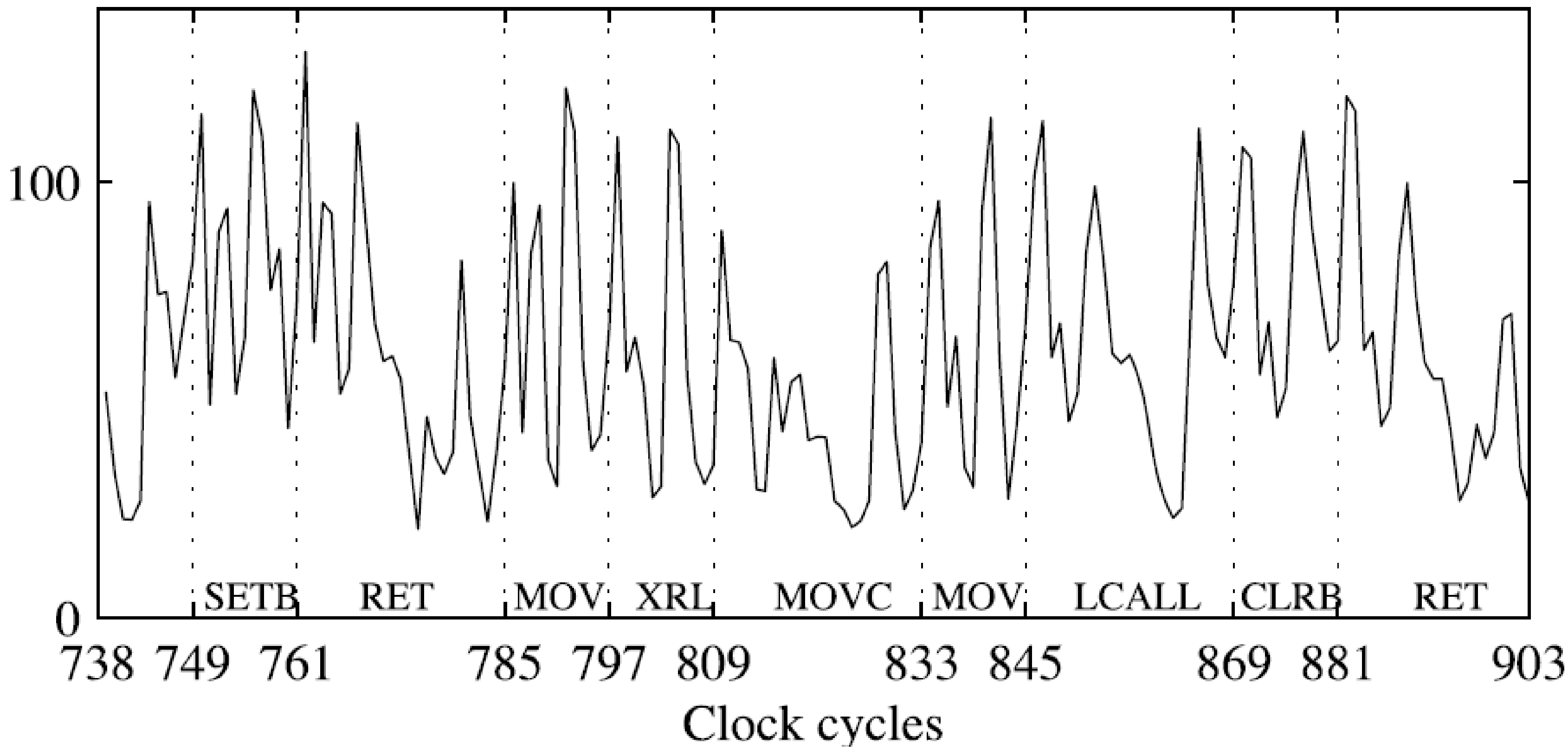
Source: DPA Book

Power Depends on Instruction, Locally

```
LCALL SET_ROUND_TRIGGER
MOV A,ASM_input + 0        ; load a0
XRL A,ASM_key + 0          ; add k0
MOVC A,@A + DPTR           ; S-box look-up
MOV ASM_input, A           ; store a0
LCALL CLEAR_ROUND_TRIGGER
```

Source: DPA Book

Power Depends on Instruction, Locally

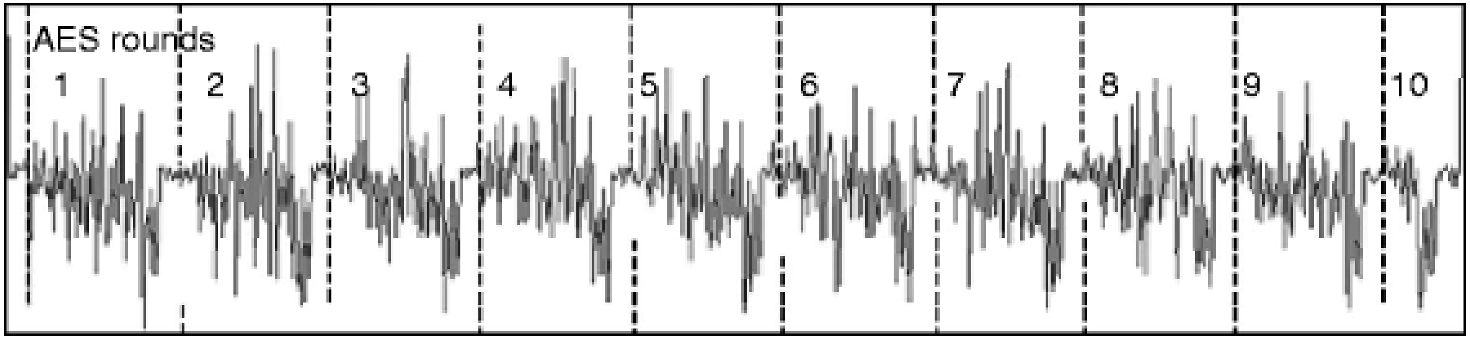


Source: DPA Book

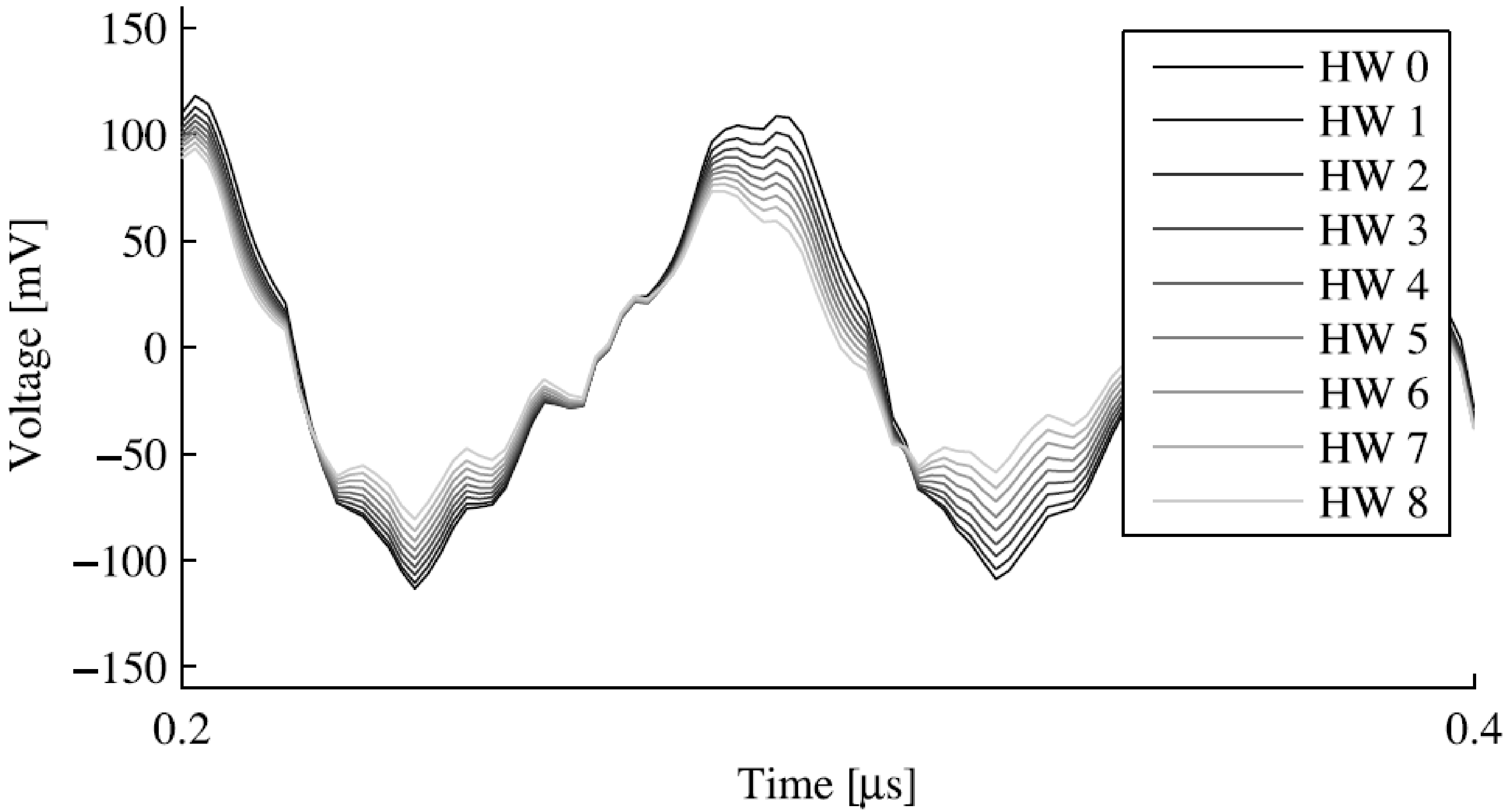
Power Depends on Instruction, Globally

Example: AES

[Joye Olivier 2011]



Power Depends on Data



Source: DPA Book

Power Analysis

- Simple Power Analysis
- Differential Power Analysis
  - Warm-up Correlation Power Analysis
  - Full Correlation Power Analysis

Power Analysis Attack Scenario

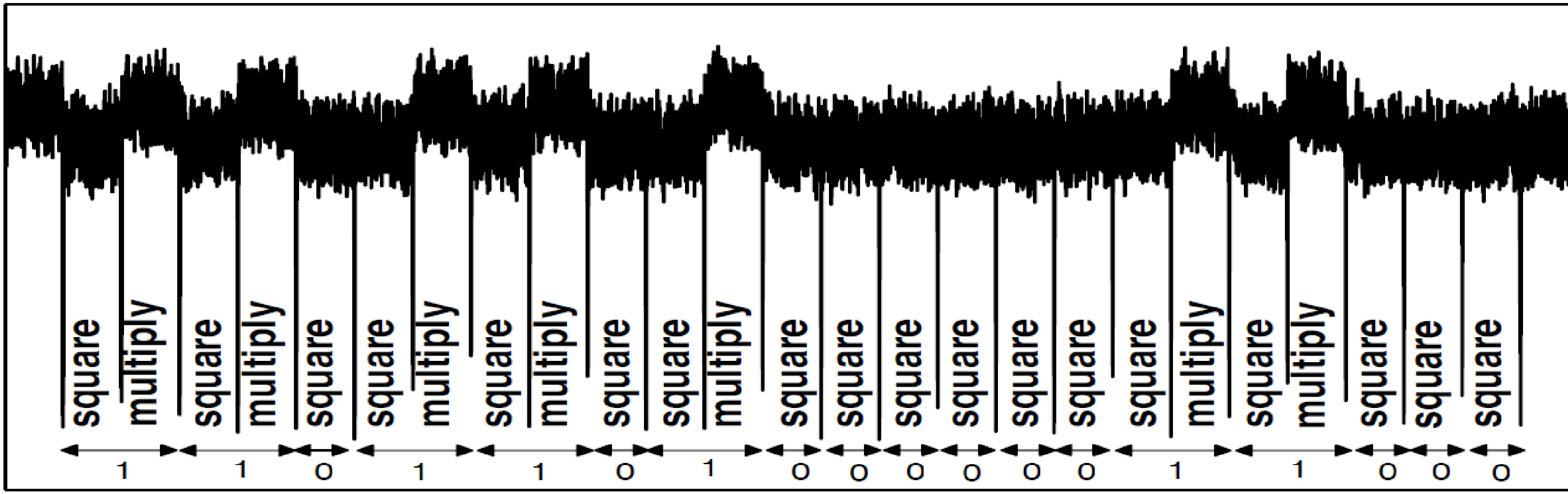
- Plaintexts and ciphertexts may be **chosen, known** or **unknown**

Theory of power analysis

- Power consumption is **variable**
- Power consumption depends on **instruction**
- Power consumption depends on **data**

Simple Power Analysis (SPA)

Example: square-and-multiply RSA exponentiation.

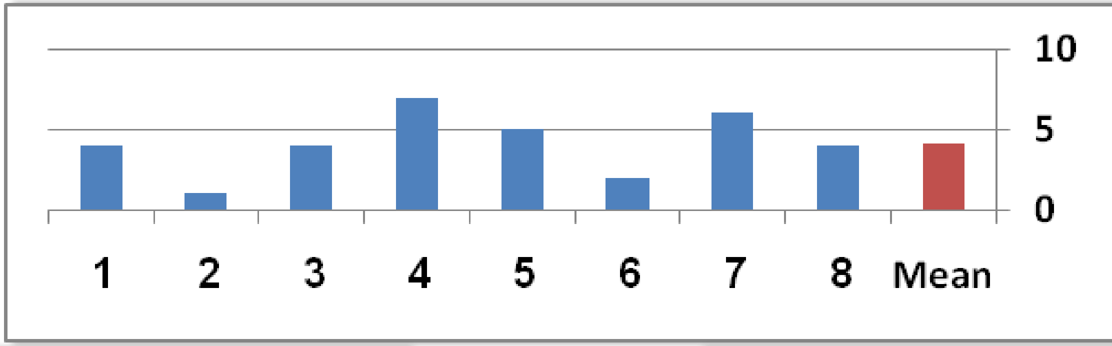


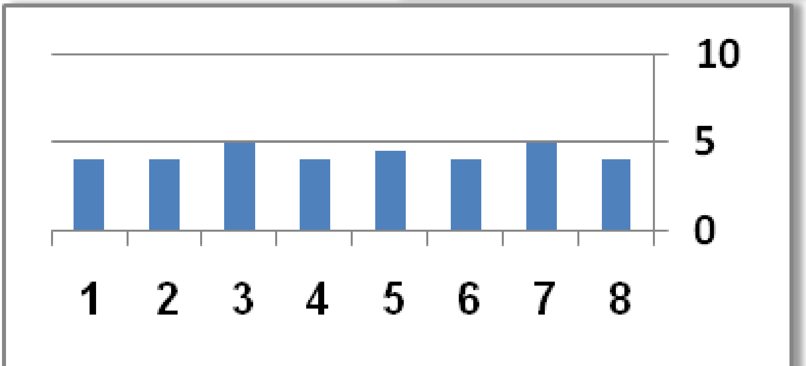
- Pros:
  - Single trace (or average of a few) may suffice
- Cons:
  - Detailed reverse engineering
  - Long manual part
  - Hard to handle bad signal-to-noise ratio, especially for small events, (e.g., AES)

Differential Power Analysis (DPA)

- Use statistical properties of traces to recover key
- Pros:
  - Very limited reverse engineering
  - Harder to confuse
- Cons:
  - Large amount of traces
- Two main types of DPA:
  - Difference of means (traditional DPA)
  - **Correlation power analysis** (CPA)

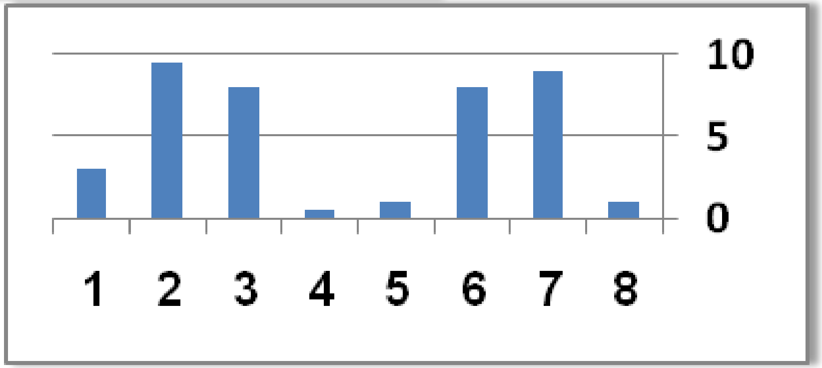
Mean, variance, correlation

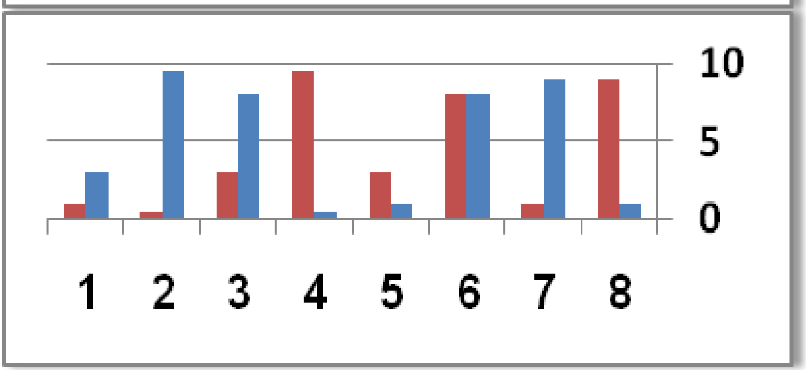




⇐ Low Variance

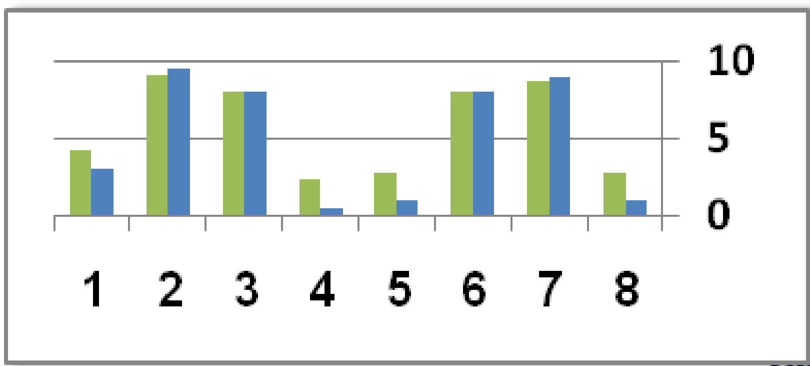
High ⇒ Variance





⇐ Low Correlation

High ⇒ Correlation



CPA Basics

- We want to discover the **correct key value (c_k)** and **when it is used (c_t)**
- Idea:
  - On the **correct time**, the power consumption of **all traces** is **correlated** with the **correct key**
  - On **other times** and **other keys** the traces should show **low correlation**

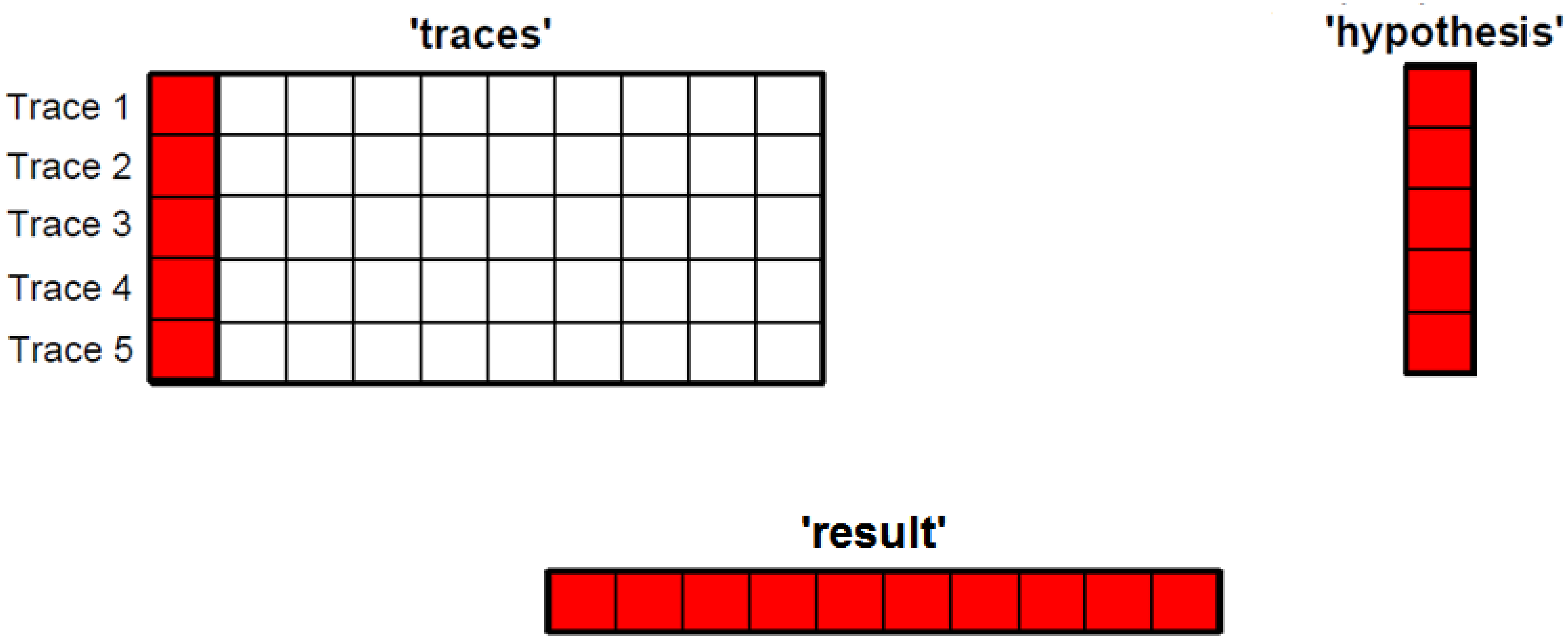
Warm-up CPA

- Assume **plaintext** and **correct key** are **known** but **correct time** is unknown
- Form **hypothesis** and test it
- Good **hypothesis function** $f(p, k)$
  - Depends on **known plaintext and**
  - Depends on **small amount of key bits**
  - **Deterministic**
  - Sufficiently random (e.g., non-linear), sensitive to small changes in p and k
- Maps to power consumption using a **power consumption model**

Warm-up CPA in Numbers

- **1000 traces**, each consisting of **1 million points**
- Each trace uses a different known plaintext – **1000 plaintexts**
- **1 known key**
- Hypothesis is vector of **1000 hypothetical power values**
- Output of warm-up CPA: vector of **1 million correlation values** with peak at $\mathbf{c_t}$

Warm-up CPA in Pictures



Full CPA

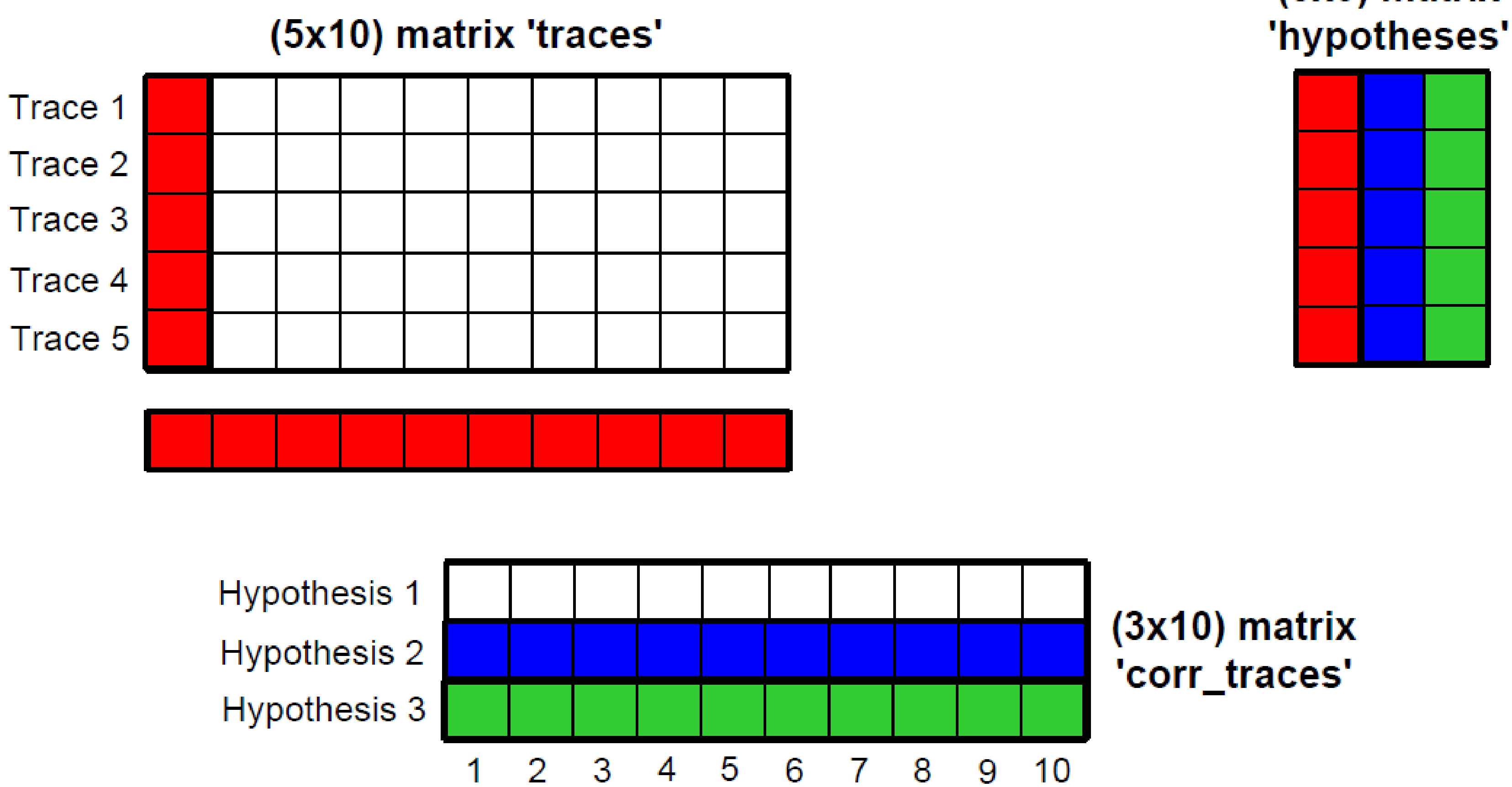
- Plaintext is **known**, but **correct key** and **correct time** unknown
- Idea: run warm-up CPA many times in parallel
- Create **many competing hypotheses**

Full CPA in Numbers

- **1000 traces**, each consisting of **1 million points**
- Each trace uses a different known plaintext – **1000 plaintexts**
- Key is unknown – **256 guesses** for first byte
- Hypothesis is matrix of **1000X256 hypothetical power values**
- Output of full CPA: matrix of **1,000,000X256 correlation values** with peak at (c_k,c_t)

Full CPA in Pictures

corr_traces = result(dpa_obj);



Full attack

- Acquire traces
- For every key fragment and corresponding hypothesis function:
  - Compute matrix of hypotheses
  - Compute correlation (score) matrix
  - Find maximum in correlation matrix and deduce value of key fragment

Discussion: effects and tradeoffs of parameters

- Number of traces
- Trace length
- Number of hypotheses (i.e., number of relevant key bits affecting the hidden state being modeled)

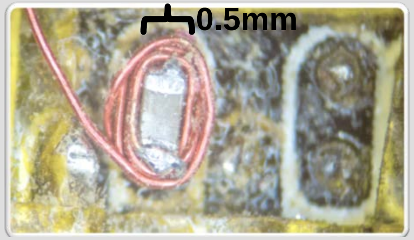
Assumptions/complications/mitigation

ASSUMPTIONS/BOTTLENECKS

- Alignment (shifts, fragmentation)
  - Handling algorithmically (e.g., cross correlation, string alignment)
  - Physical synchronization via triggering
- Data size: #traces, trace length
- Assuming fixed over all traces:
  - Key
  - Computation progress and flow
- Measurement quality
  - Physical access, noise, transmission
  - Equipment cost
  - Expertise

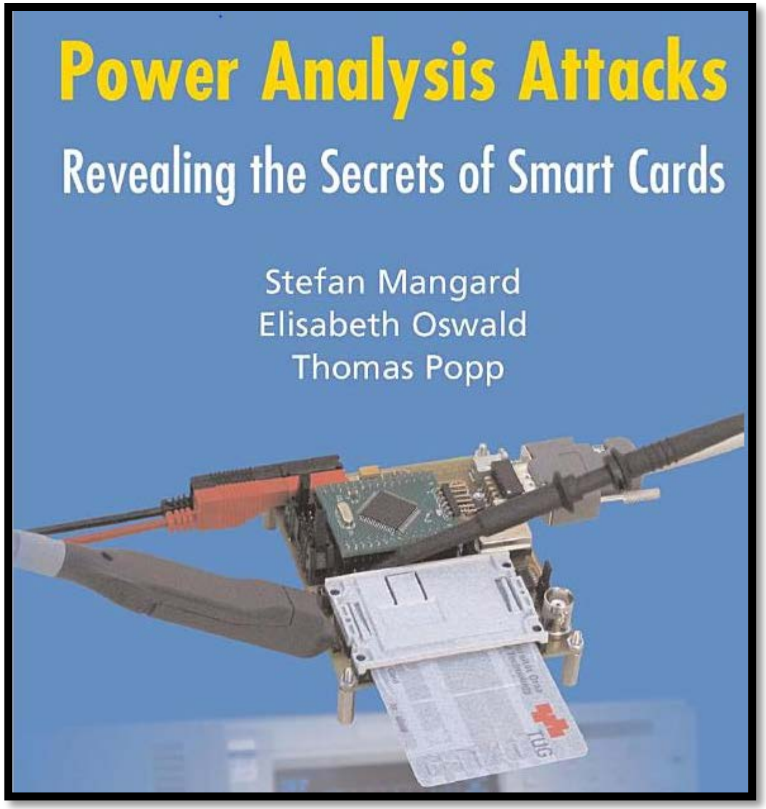
MITIGATIONS

- Timing
  - Unstable clock
  - Randomize control/instruction flow
  - Insert random/key/plaintext-dependent delays
- Change protocol to roll keys often
- Add power noise



Example: probing an “decoupling capacitor” (SMD 0402) close to the microcontroller chip. [O’Flynn 2013]

Further Reading



http://www.dpabook.org

http://www.springerlink.com/content/g01q1k